DRAFT
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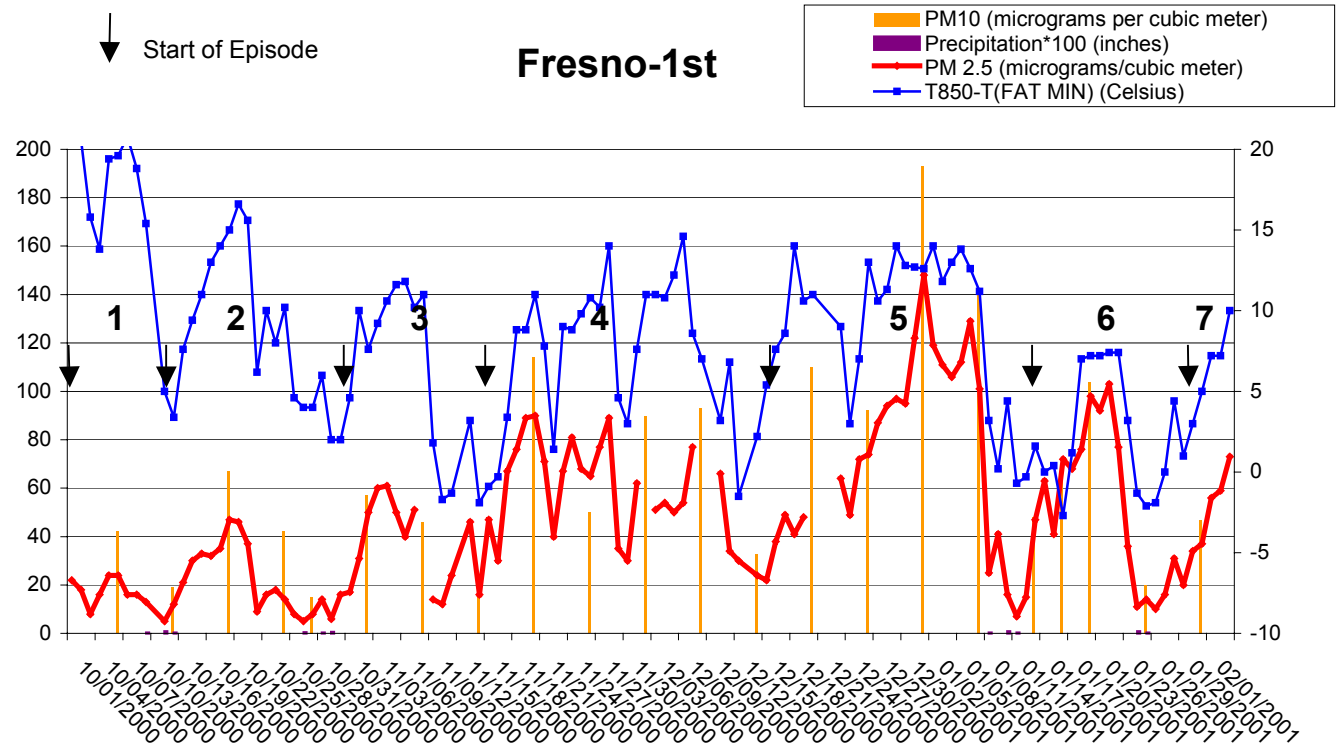
CRPAQS SYNOPTIC SUMMARY

The CRPAQS fall and winter measurement periods can be divided into seven distinct episodes. These episodes, characterized by limited atmospheric dispersion, were separated by vigorous trough passages. Analysis of synoptic events shows that once a particulate episode begins, a deep trough must traverse the region at both the upper levels of the atmosphere and at the surface as a cold frontal boundary in order to significantly decrease Particulate Matter (PM) concentrations. These types of troughs are normally associated with strong vertical mixing, moderate to high boundary layer mixing heights, precipitation, and wind speed and directional sheer within the boundary layer.

The meteorological analysis for CRPAQS utilized synoptic analyses, precipitation patterns, and atmospheric stability parameters to determine episode strength and periodicity. Analysis of $PM_{2.5}/PM_{10}$ ratios and nitrate levels reveal that when the overnight minimum temperature decreased to below 40 degrees Fahrenheit, coupled with significant warming aloft, fine particulate levels climbed. When prolonged periods of these conditions occurred, $PM_{2.5}$ levels climbed above the NAAQS. In even stronger more persistent stability regimes, PM_{10} exceeded the NAAQS. Figure 1 shows precipitation, $PM_{2.5}$, PM_{10}, and stability parameters for the CRPAQS period at the Fresno-1st site. General patterns in these parameters where also evident at other sites. Precipitation events also influenced PM concentrations during CRPAQS. For the CRPAQS period, when a frontal system was strong enough to produce precipitation of 0.10 inch or more of liquid water, 24 hour averaged $PM_{2.5}$ concentrations dropped to below 15 $\mu g/m^3$.

Figure 1.



The synoptic meteorological parameters analyzed to determine the behavior of particulate matter were 850 MB temperature stability (T850 Stability ^{0}C), 500 MB height (decameters), and precipitation (inches). The 850 MB temperature stability parameter was utilize because 850 MB temperature (approximately 5,000 feet) minus the minimum surface temperature is a good indicator of the inversion strength, the mixing layer depth, and whether air is being warmed from a synoptic subsidence inversion aloft. This inversion is commonplace when a ridge builds along the West Coast of California, providing general adiabatic warming of subsiding air over the region. In Hackney, et al, an analysis was conducted on the relationship of historical 850 MB temperatures and PM measurements. Hackney, et al, determined that in the San Joaquin Valley, when 850 MB temperatures in the fall were above +15^0 C and +10^{0}C during the winter (late November or December to February) an episode was possible. A stronger indication for a PM episode to occur is when 850 MB temperatures were above +18^{0}C in the fall and above +14^{0}C in the winter.

500 MB height is also important in that it is directly correlated to the temperature of the entire column of air. During periods of high pressure aloft, flows at the surface are usually light and accompanied by low mixing depths. The 500 MB height and placement of the mean ridge and trough patterns reflect PM amounts and trends. In Hackney, et al, it was determined that a height of 5,760 meters in the San Joaquin Valley is sufficient to suspect an episode, and that a height of 5,820 meters or more in the Valley made an episode occurrence a likelihood.

Precipitation measurements were also analyzed as an indicator of the vigorous trough passages, which provided enough vertical mixing to produce rainfall. As mentioned before, the strength of the frontal system and trough, was a good indicator of how much PM dispersion occurred.

Table 1 shows for each peak day within the seven episodes, the PM values, meteorological parameters, and episode duration. The major episode of CRPAQS, when PM10 exceeded the NAAQS, was manifested by cool overnight lows near 32 degrees Fahrenheit and warm air aloft for an extended period of time. These conditions persisted from December 17th through January 7th. During this time, PM steadily increased to a peak value at Fresno ($PM_{2.5}$ = 148 $\mu g/m^3$ and PM_{10} = 193 $\mu g/m^3$) and Bakersfield-Residential ($PM_{2.5}$ =133$\mu g/m^3$) on the 1st of January. During this period in urban areas, initial analysis of speciation data show high carbon and ammonium nitrate levels. The combination of an 850 MB temperature ridge aloft along with low minimum temperatures resulted in strong inversions trapping pollutants in a shallow mix layer. The high carbon levels could have been due to holiday residential wood combustion. In addition, under these cold and poor dispersion conditions, nitrate levels measured on the real-time instruments were the highest of the study.

TABLE 1: CRPAQS EPISODE EVENT SUMMARY TABLE

Episode Number	Date	PM10	PM2.5	T850 Stability (^{0}C)	Minimum (^{0}F)	500 MB Height	Episode Duration (days)
1	10/1-10/12	42(6th)	24(5th&6th)	2.4	63	578	**12**
2	10/13-10/30	67(18th)	47(18th)	6.8	54	578	18
3	10/31-11/15	57(2nd)	61(4th)	2.3	47	575	17
4	11/16-12/15	114(20th)	90(20th) 89(28th)	9.3 6.2	35 46	576 572	28
5	12/16-01/12	193(1st)	148(1st)	12.6	32	574	26
6	01/13-01/27	104(19th)	103(21st)	3.9(19th) 6.8(21st)	38(19th) 33(21st)	571(19th) 569(21st)	15
7	01/28-02/03	47(31st)	73(3rd)	3.9(31st) 6.1(3rd)	34(31st) 39(3rd)	568(31st) 580(3rd)	**7**

One basis for understanding the behavior of particulate matter evolution is to analyze the synoptic situation that is driving the local effects of dispersion and transport. These synoptic descriptions follow.

Episode 1: Sunday, October 1 -Thursday, October 12

From the 1st to the 8th, episode #1 was marked by a mean, broad ridge anchored across the eastern Pacific and California, which brought moderate stability and low to moderate mixing heights. This ridge was low in amplitude, resulting in moderate subsidence. An inverted thermal surface trough developed from Bakersfield curving northwestward to Redding. This pressure pattern was representative of calm overnight winds, and thermally driven light afternoon northwesterly flow. During this initial episode, $PM_{2.5}$ values average near 20 $\mu g/m^3$ and measured PM_{10} concentration at Fresno was 42 $\mu g/m^3$ on the 6th. The 500 MB height of 578 dm on the 6th was conducive of a high PM event, whereas, the 850 MB stability parameter of +2.4 Celsius (T850 MB = $+20^0$C) was indicative of the likelihood of an event. As is evident in the low T850 MB stability parameter, the inversion and resulting stability was not strong enough to trap and elevate PM readings, thus resulting in PM levels remaining well below the standard.

A significant early season trough moved into the region on the 9th, bringing increasing instability and boundary layer flow. Within the next couple of days, the 9th to the 12th, a series of disturbances embedded within the mean trough traversed central California bringing increased wind flow, higher boundary layer mixing heights, and precipitation. The most noteworthy precipitation during this period occurred on the 11th, when a second short wave embedded within the mean trough across California crossed the Valley and produced 0.76 inches of precipitation.

Episode 2: Friday, October 13 –Monday, October 30

Episode #2 was marked by high pressure rapidly building into the region on the 13th and persisting through the 20th. This episode was unique in that the central California was under the influence of both the eastern Pacific and Four Corners ridge during the peak episode day. This pattern resulted in weak thermally driven flow at the surface and general synoptic subsidence aloft. As a result, under light to moderate stability, T850 stability parameter of +2.8 ^{0}C (T850 MB = 15^0C), moderately high 500 MB heights (578 MB) and low mixing depths, PM climbed and reached a maximum concentration in Fresno at PM_{10} – 67 $\mu g/m^3$ and $PM_{2.5}$ – 47 $\mu g/m^3$ and Bakersfield at $PM_{2.5}$ – 30 $\mu g/m^3$ on the 18th. According to Hackney, et, al, the 850 MB temperature and 500 MB heights reached the criteria to suspect an episode. As is evident in the PM measurements the state standard was exceeded in Fresno on the 18th.

The ridge began to breakdown on the 20th as weak disturbances traversed the ridge and formed a closed low over the Great Basin on the 24th. Another stronger trough moved into the region on the 25th bringing moderate boundary layer flow, vigorous vertical mixing, and periods of precipitation through the 30th. With the trough passage on the 29th, Fresno recorded the maximum amount of precipitation during the episode of 0.55 inches.

Episode 3: Tuesday, October 31 –Wednesday, November 15

Episode #3 began on the 31st as a strong ridge developed along the West Coast. The ridge axis remained offshore during this episode leading to downstream subsidence and increasing stability. During the peak PM event of episode #3, Bakersfield's PM values were lower than Fresno due to a closed low circulation over northern Baja, creating some upper level mixing and neutral to light instability over southern California. As a result, the peak $PM_{2.5}$ levels at Bakersfield Residential were 45 $\mu g/m^3$, with a T850 MB stability parameter of +1.4 ^0C (T850 MB = +9.2 ^0C) and 500 MB height of 575 dm on the 3rd and at Fresno First PM_{10} measurement of 57 $\mu g/m^3$ on the 2nd and $PM_{2.5}$ measurement 61 $\mu g/m^3$, with a 850 MB stability parameter of +2.3 ^0C (T850 MB = +10.6 ^0C) and 500 MB height of 575 dm on the 4th.

In both Fresno and Bakersfield, according to Hackney et, al, the T850 MB and 500 MB heights do not suggest an episode under a fall regime; however, the PM10 measurement in Fresno exceeded the standard on the 2nd. Whereas, comparing Hackney et, al, results under a winter regime to the observed T850 MB, their conclusion supported a minor PM episode. Due to early season rainfall and a general cooling of the lower levels of the atmosphere, the transition from the fall to the winter regime took place during this time.

PM levels steadily lowered as the upper level ridge and surface high pressure gradually weakened and moved eastward. An unseasonably cold trough (540 dm at OAK) and a vigorous, dry cold front from the Gulf of Alaska moved into the region on the 9th, bringing increased boundary layer flow and deep mixing. This system was moisture starved and resulted in trace amounts of precipitation across the region. The frontal system and accompanying trough were strong enough to bring an end to the 3rd episode as deep mixing scoured the area. Multiple embedded disturbances within this trough traversed the region bringing unstable conditions, good dispersive conditions, and moderate boundary layer flow and mixing heights into the 15th.

Episode 4: Thursday, November 16 –Friday, December 15

Episode #4 began on the 16th and was marked by a moderate ridge building along the West Coast bringing increasing stability and offshore flow. During CRPAQS the 4th episode was the longest period at 28 days.

Stability and PM values steadily increased to the highest measured values of the episode on the 20th and 21st of November, with a secondary peak occurring on the 28th. This episode was separated into two peaks due to a trough developing over the Great Basin on the 22nd dispersing some of the PM which had built up over the region. Fresno and Bakersfield peak $PM_{2.5}$ measurements were observed on the 20th at 90 $\mu g/m^3$ and on the 21st at 96 $\mu g/m^3$, respectively. The highest measured PM_{10} during this episode was at Fresno on the 20th with a value of 114 $\mu g/m^3$. Fresno $PM_{2.5}$ measurement reached a secondary peak on the 28th at 89 $\mu g/m^3$. This episode was separated into

two peaks due to a trough developing over the Great Basin on the 22nd dispersing some of the PM which had built up over the region.

According to Hackney, et., al, the 850 MB temperature measured +11^{0}C and +14^{0}C on the 20th and 28th, respectively, were representative of an PM episode occurring, whereas, the 500 MB heights of 576 and 572 dm, were indicative of a weak PM episode. During this episode, the state standard was exceeded.

This episode was characterized by a mean mid-tropospheric ridge positioned along the West Coast, with brief drop in the PM measurements on the 29th and 30th, when a dry, front passed to the north of the area dropping to $PM_{2.5}$ measurements at Fresno to 35 $\mu g/m^3$ on the 30th and Bakersfield to 22 $\mu g/m^3$ on the 29th.

The ridge began to breakdown late on the 7th, bringing decreasing stability, better dispersion, and lowering PM concentrations. A series of weak disturbances traversed the region from the 7th through the 15th, bringing very light precipitation to Fresno (total = 0.07 inches), increased boundary layer flow and mixing depths, which brought an end to the episode #4.

Episode #5: Saturday, December 16 –Friday, January 12

Episode #5 began on the 16th and was marked by the West Coast ridge building into California, resulting in lowering boundary layer mixing heights and increasing stability. PM region-wide uniformly increased with 500 MB heights and stability, with a minor intra-episode peak, with PM_{10} measurement at Fresno of 110 $\mu g/m^3$ and $PM_{2.5}$ measurement at Bakersfield Residential of 58 $\mu g/m^3$, occurring on the 20th. A weak upper level disturbance briefly broke down the ridge on the 24th resulting in slightly lower $PM_{2.5}$ measurements in Fresno at 49 $\mu g/m^3$ and Bakersfield 40 $\mu g/m^3$. After this weak trough passage, the ridge rebuilt in earnest and moderate stability and low mixing heights continued through the end of the episode on January 7th.

During this episode the maximum PM measurements of the CRPAQS period were observed. The general synoptic pattern during this episode was strong high pressure aloft positioned along the West Coast providing a general area of subsidence and stable weather over the region, with an accompanying strong surface high located over Idaho. With high pressure over the Intermountain Region and lower pressures over the eastern Pacific, moderate offshore flow developed. Typically with this type of flow pattern, the normal nocturnal inversion at the surface is reinforced with a subsidence inversion aloft, created by adiabatic warming off the Sierra's and general subsidence from the ridge.

The peak measurements of the fifth episode were recorded on the 1st and 7th with PM_{10} measurements at Fresno of 193 $\mu g/m^3$ (1st) and 141$\mu g/m^3$ (7th). $PM_{2.5}$ measurements at Fresno of 148 $\mu g/m^3$ (1st) and 101 $\mu g/m^3$ (7th) and Bakersfield Residential at 133 $\mu g/m^3$ (1st) were also recorded. These high PM values corresponded with the highest 850 MB stability (+13.4 C at Oakland) measured during the CRPAQS period, which occurred on the 2nd. The 850 MB temperature was very warm during this episode. At Oakland

at 12Z, the 850 MB temperature was +13 ^{0}C. This is representative of a strong PM episode. The 500 MB height was not indicative of a strong episode. At 574 dm, the value was not conducive to a significant PM episode. The combination of weak offshore flow and mid-tropospheric stability, elevated the PM readings experienced across central California.

A significant trough moved into the region on the 8th, with accompanying rainfall in Fresno of 0.31 inches and Bakersfield of 0.29 inches. A series of disturbances within the trough traversed the region from the 8th to the 12th adequately dispersing the PM that had built up over the region during the episode and lowered $PM_{2.5}$ measurements into the upper teens by the 10th in both Fresno and Bakersfield.

Episode 6: Saturday, January 13 –Saturday, January 27

High pressure and increasing subsidence once again moved into the region on the 13th bringing increasing PM levels and leading to the beginning of the episode #6. This episode was characterized by ridging through the 17th, resulting in building $PM_{2.5}$ values into the lower 60's $\mu g/m^3$ range. Shortly thereafter, more pronounced ridging and decreasing dispersion occurred on the 18th, when 500 MB heights climbed to near 578 dm with an 850 MB stability indices of +7 °C (850 MB temperature of +7^{0}C). The 500 MB height was conducive of an episode occurring, but the 850 temperature was not conducive of an episode. This peak in meteorological parameters corresponded with the highest recorded PM_{10} measurement of the episode at Fresno at 104 $\mu g/m^3$ on the 19th.

$PM_{2.5}$ peaked at Fresno on the 21st with a measurement of 103 $\mu g/m^3$ and also in Bakersfield Residential on the 22nd at 103 $\mu g/m^3$. The southward progression of the peak $PM_{2.5}$ values can be accounted for by the pre-frontal / trough stability that progressively moved down-valley with the approach of the next system from the eastern Pacific on the 23rd.

A series of disturbances embedded within the trough moved through the region from the 23rd to the 27th, with adequate boundary layer mixing heights, moderate instability, and moderate southeasterly flow, dispersing PM levels into the low teens. From the 23rd to the 25th, a series of strong cold frontal systems brought 1.19 inches of rainfall at Fresno, bringing an end to the 6th episode. The highest recorded rainfall during the trough passage occurred on 0.85 inches on the 24th.

Episode 7: Sunday, January 28 –Saturday, February 3

The final (7th) episode of CRPAQS began on the 28th, when strong high pressure built along the West Coast. Light boundary layer flow and increasing 850 MB stability resulted in $PM_{2.5}$ levels gradually climbing into the early part of February. $PM_{2.5}$ measurements of 73 $\mu g/m^3$ in Fresno on the 3rd and 92 $\mu g/m^3$ in Bakersfield on the 4th marked the buildup that occurred during this episode.